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Non-universal scalar masses: a signal-based analysis for the Large Hadron Collider

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Abstract: We study the possible signatures of non-universal scalar masses in supersymmetry at the Large Hadron Collider (LHC). This is done, following our recent study on gaugino non-universality, via a multichannel analysis, based largely on the ratios of event rates for different final states, aimed at minimizing irregularity in the pattern due to extraneous effects and errors. We have studied (a) squark-slepton non-universality, (b) non-universality in sfermion masses of the third family, (c) the effects of $SO(10)$ D-terms in supersymmetric Grand Unified Theories. After presenting an elaborate numerical analysis of like- and opposite-sign dileptons, inclusive and hadronically quiet trileptons as well as inclusive jet final states, we point out specific features of the spectrum in each case, which can be differentiated in the above channels from the spectrum for a minimal supergravity scenario with a universal scalar mass at high scale. The event selection criteria, and the situations where the signals are sizable enough for a comparatve study, are also delineated. It is found that, with some exceptions, the trilepton channels are likely to be especially useful for this purpose.

Keywords: Supersymmetric Standard Model, GUT, Supersymmetry phenomenology, Hadronic Colliders .

Contents

1. Introduction

With the Large Hadron Collider (LHC) likely to become operative in the immediate future, it is of great importance to sharpen the prediction and analysis of different types of physics beyond the standard model (SM). This consideration applies especially to supersymmetry (SUSY), because (a) SUSY is one of the most frequently explored options for new physics, and (b) a large variety of SUSY scenarios offer themselves as candidate theories, often substantially different from each other in their phenomenological implications [1–4].

The much-advertised merits of SUSY, and at the same time the concerns voiced in connection with it, lead to the expectation of the following features:

- Stabilization of the electroweak scale.
- The existence of a cold dark matter candidate.
- The possibility of paving the path towards a Grand Unified Theory (GUT).
- Relating SUSY to some overseeing physics at the Planck scale, or a similarly high scale of energy.
- Ensuring the suppression of flavour-changing neutral currents (FCNC).

The first of these features necessitates a spectrum of new particles, at least the gauginos, higgsinos and the third family of squarks and sleptons, within the TeV scale. The second requirement is a motivator towards conserved R-parity, defined as $R = (-1)^{(3B+L+2S)}$ [5]. While the ambition for GUT inspires one to envision the SU(3), SU(2) and U(1) gaugino masses (together with the corresponding gauge couplings) as related at a high scale, the scalar (or sfermion) masses also may be traced to some high-scale origin if physics at that scale subsumes the low-energy SUSY scenario [4, 6, 7]. And finally, the scalar spectrum of SUSY may be subject to specific constraints if FCNC processes are to be suppressed [8]. It is with the above requirements in view that some simplified models of SUSY breaking are pursued, of which the most popular one is one conserving R-parity and based on minimal supergravity (mSUGRA) with universal scalar and gaugino masses at the energy scale where SUSY is broken in a postulated 'hidden sector' [4, 9]. Since one is not sure whether TeV-scale physics is indeed dictated by an idealization of the above form, an important question to ask is: can the departure from a scenario with universal scalar and gaugino masses (such as in mSUGRA) be reflected in signals observed at the LHC?

Although this question has been explored in earlier works, the need of systematic analyses, based primarily on observable signals, still remains. In an earlier study, we have investigated the effects of departure from gaugino universality (even within the ambit of a SUSY-GUT scenario) on various signals at the LHC, and identified situations where a multichannel analysis can reveal traces of such departure [10]. In the present work, we take up a similar investigation of departure of the squark and slepton spectrum from that predicted by mSUGRA. A number of theoretical scenarios have already been investigated in this connection. These include, for example, scenarios with heavy scalars [11–14] or some superstring-inspired models [15]. In addition, one finds studies on the phenomenological implications of non-universal scalars [16, 17], particularly relating to dark matter [18]. The special thrust of the present work lies in its generality as well as the emphasis on the relative strengths of different signals in eliciting a non-universal scalar mass pattern.

The most important signals of R-parity conserving SUSY consist in large missing transverse energy $\not{E}_T$, accompanied with energetic jets and leptons of various multiplicity in the central region. While the signal strengths, kinematics and event topology of a given final state yield information of the mass scale of new particles, it is emphasized that *the relative strengths of different signals corresponding to the spectrum of a given type often tells us more.* In particular, the departure from the mSUGRA scenario can crucially affect some particular final state. Hence we advocate the detailed exploration of the 'signature space' [10, 19–25] as a whole, and illustrate such exploration for some representative cases through a multichannel analysis [26].

Our (restricted) signature space consists of the following finals states: $jets + \not{E}_T$, *same-sign* as well as *opposite-sign dileptons*, and *trileptons* along with $jets + \not{E}_T$. In addition, we include the so-called 'hadronically quiet' trilepton events in our analysis. The event rates predicted are after the imposition of cuts aimed at reducing the SM backgrounds. We present the ratios of various types of final states, thus also reducing uncertainties due to parton distributions, factorization scales, jet energy resolutions etc. These ratios,

presented as bar graphs, demonstrate the departure (or otherwise) from what is predicted in mSUGRA, for superparticle masses in different combinations. They can be supplemented by the absolute rates, too, for (a) information on the overall SUSY masses, and (b) cases where the rate of one type of event is either too small or submerged in backgrounds.

In the mSUGRA models, all low-scale parameters are derived from a universal gaugino mass ($M_{1/2}$), a universal scalar mass (m_0), the trilinear soft SUSY-breaking parameter (A_0) and the sign of the Higgsino mass parameter ($\text{sgn}(\mu)$) for each value of $\tan\beta$, the ratio of the two Higgs vacuum expectation values (vev) [4, 9]. Since the consequence of gaugino non-universality [10, 27–31] has been probed in our earlier work, the gauginos have been taken to have a universal mass at high scale in this study.

Specifically, we consider three different types of non-universal scenarios. These are (a) non-universality of the squark and and slepton masses, (b) non-universality of the third family sfermions with respect to the first two, and (c) non-universality due to high-scale D-terms, pertinent to an $SO(10)$ model. While the first scenario is purely phenomenological, the second one is motivated by the so-called 'inverted hierarchy' at a high scale, which is advocated as a solution to the flavour problem [32–36]. The third case concerns a particular theoretical picture where physics between the Planck and GUT scales affects the masses of sfermions in different sub-representations of $SO(10)$, leading to different low-energy mass patterns [37–39].

The approach advocated here can be useful in so called 'inverse problem' approach [40], where one aims to construct an underlying theory from a multichannel assortment of data.

The paper is organized as follows. In the following section, we outline the general strategies of our collider simulation, including the main event selection criteria. We discuss the non-universality of squark-slepton masses and the different predictions in the signature space in section 3. Section 4 contains a comparative study of different signals at the LHC, when the non-universality is limited to scalars in the third family. Signatures of $SO(10)$ D-terms leading to non-universality is discussed in section 5, where we also discuss the variation of the mass spectrum with the D-term contribution treated as a free parameter. We summarize and conclude in section 6. Salient features of the particle spectra in the different cases, and the absolute rates of predicted events, are presented in Appendices A and B, respectively.

2. Strategy for simulation

Before we proceed to analyze specific scenarios, let us summarize the collider simulation procedure that has been adopted in all the cases. The spectrum generated by `SuSpect` v2.3 [41] as described in each scenario is fed into the event generator `Pythia` 6.405 [42] by `SLHA` interface [43] for the simulation of pp collision with centre of mass energy 14 TeV.

We have used `CTEQ5L` [44] parton distribution functions, the QCD renormalization and factorization scales being both set at the subprocess centre-of-mass energy $\sqrt{\hat{s}}$. Other options such as the scales set at the average mass of the particles produced in the initial hard

scattering are not found to alter the qualitative features of our results. All possible SUSY processes and decay chains consistent with conserved R-parity have been kept open. In the illustrative study presented here, we have switched off initial and final state radiations. This does not affect the major conclusions, as events with $\geq$2 jets are mostly considered and jet counting is not of any crucial significance here.The effect of multiple interactions has been neglected. However, we take hadronization into account using the fragmentation functions inbuilt in `Pythia`.

The final states studied here are [21, 25, 45]:

- Opposite sign dilepton (OSD) : $(\ell^{\pm}\ell^{\mp}) + (\geq 2)\ jets\ + E\!\!\!/_T$
- Same sign dilepton (SSD) : $(\ell^{\pm}\ell^{\pm}) + (\geq 2)\ jets\ + E\!\!\!/_T$
- Trilepton ($3\ell + jets$): $3\ell\ + (\geq 2)\ jets\ + E\!\!\!/_T$
- Hadronically quiet trilepton (3ℓ): $3\ell\ + E\!\!\!/_T$
- Inclusive jets ($jets$): $(\geq 3)\ jets\ + X + E\!\!\!/_T$

where ℓ stands for electrons and or muons.

It should be noted that hadronically quiet trileptons have been introduced as a separate channel of study here, contrary, for example, to the one presented in reference [10]. The reason for our optimism about this channel is the fact that the very notion of sfermion non-universality entails scenarios with sleptons that are light with respect to charginos and neutralinos, a feature that serves to enhance the rates of final states with high lepton multiplicity arising from decays of the latter. The numerical results presented in the following sections show that, with exceptions, this optimism is not entirely misplaced.

We have generated all dominant SM events in `Pythia` for the same final states, using the same factorization scale, parton distributions and cuts. $t\bar{t}$ production gives the most serious backgrounds in all channels excepting in the trilepton channels, for which electroweak backgrounds can be serious. For the inclusive jet signals, the final states without any isolated, central, hard leptons are also prone to large QCD backgrounds, where, for example, jet energy mismeasurement can lead to a tail with missing-E_T. The maximum reduction of such QCD backgrounds is very challenging (especially due to uncertainties in the prediction and interpretation of multi jets). In our theoretical study, keeping the above problem in mind, we have tried to be conservative by imposing a cut of 100 GeV on *each jet* and not choosing to order their hardness cuts. While one can further improve on this by making the $E\!\!\!/_T$ cut even higher, our main message, namely, the sensitivity of the ratios of various signals to different non-universal scenarios, still retains its relevance after such improvements.

The signal and background events have been all calculated for an integrated luminosity of 300 fb^{-1}. As noted earlier, the event ratios which are the primary objects of our analysis help in avoiding uncertainties in prediction. Cases where the number of signal events in any of the channels used in the ratio(s) is less than three have been left out. Also, in the

histograms (to be discussed in the next section), cases where any of the entries in the ratio has a significance less than 2σ have been specially marked with a # in the bar graphs. since our observations on them may still be useful if statistics can be improved.

The cuts used in our analysis are as follows:

- Missing transverse energy $\not{E}_T \geq$ 100 GeV.
- ${p_T}^l \geq$ 20 GeV and $|\eta_\ell| \leq$ 2.5.
- An isolated lepton should have lepton-lepton separation $\triangle R_{\ell\ell} \geq 0.2$, lepton-jet separation $\triangle R_{\ell j} \geq 0.4$, the energy deposit due to jet activity around a lepton E_T within $\triangle R \leq 0.2$ of the lepton axis should be ≤ 10 GeV.
- ${E_T}^{jet} \geq$ 100 GeV and $|\eta_{jet}| \leq$ 2.5
- For the hadronically quiet trilepton events, we have used in addition, invariant mass cut on the same flavour opposite sign lepton pair as $|M_Z - M_{l_+ l_-}| \geq 10$ GeV.

where $\triangle R = \sqrt{\triangle\eta^2 + \triangle\phi^2}$ is the separation in pseudo rapidity and azimuthal angle plane.

Jets are formed in `Pythia` using `PYCELL` jet formation criteria with $|\eta_{jet}| \leq 5$ in the calorimeter, $N_{\eta_{bin}} = 100$ and $N_{\phi_{bin}} = 64$. For a partonic jet to be considered as a jet initiator $E_T > 2$ GeV is required while a cluster of partonic jets to be called a hadron-jet $\sum_{parton} {E_T}^{jet}$ is required to be more than 20 GeV. For a formed jet the maximum $\triangle R$ from the jet initiator is 0.4.

We have checked the hard scattering cross-sections of various production processes with `CalcHEP` [46]. All the final states with jets at the parton level have been checked against the results available in [21]. The calculation of hadronically quiet trilepton rates have been checked against [47], in the appropriate limits.

3. Squark-slepton Non-universality

Here we select a scenario where the squarks and slepton masses at low-energy are results of evolution from mutually uncorrelated mass parameters ($m_{0\tilde{q}}$ and $m_{0\tilde{l}}$ respectively) at a high scale. Although this is a purely phenomenological approach, it is helpful in the sense that it embodies the complete independence of the coloured and uncloured scalar masses at the high scale, while still achieving some simplification of the parameter space, by avoiding a random proliferation of low-energy masses. The choice of parameters made in this manner takes all collider and low-energy constraints into account, as summarized in the subsection below.

3.1 Choice of SUSY parameters

As has been already indicated, we have confined ourselves to R-parity conserving supersymmetry where the lightest neutralino is the LSP. The squark-slepton spectrum is generated by `SuSpect` v2.3 [41] with the **pMSSM** option, where a separate mass parameter for

squarks and sleptons is assumed at the high scale. The Higgs mass parameters $m^2_{H_u}$ & $m^2_{H_d}$ are also taken to evolve from the high-scale slepton mass. We tune the non-universal scalar masses and gaugino masses at the GUT scale such that the following combinations arise:
$(m_{\tilde{g}}, m_{\tilde{q}^{1,2}})$ = (500,500), (500,1000) and (1000,1000) where $m_{\tilde{g}}$ is the gluino mass and $m_{\tilde{q}^{1,2}}$ denote the (approximately degenerate) squark masses of the first two families at the electroweak symmetry breaking (EWSB) scale defined by the 'default option' in `SuSpect`, i.e. $\sqrt{m_{\tilde{t_L}} m_{\tilde{t_R}}}$. All the above masses are in GeV. All the aforementioned sets are studied for three non-universal slepton masses of the first two families $m_{\tilde{l}^{1,2}}$ (approximately degenerate) at the low-scale, namely, 250 GeV, 500 GeV and 750 GeV with $\tan\beta$= 5 and 40 for each choice. The high-scale value of the soft trilinear parameter (A_0) has been set at zero, a practice that has been followed in the subsequent sections, too (For details see table A1 and A2).

Radiative electroweak symmetry breaking has been ensured in each case, after which the positive value of μ has been chosen for illustration, in this section as well as in the subsequent ones. One also achieves gauge coupling unification at high scale and consistency with laboratory constraints on a SUSY scenario. Consistency with low-energy FCNC constraints such as those from $b \to s\gamma$, and also with the data on muon anomalous magnetic moment are checked for every combination of parameters [48, 49] used in the analysis. No constraints from dark matter have been included here. We have used the strong coupling $\alpha_3(M_Z)^{\overline{MS}} = 0.1172$ for this calculation which is again the default option in `SuSpect`. Throughout the analysis we have assumed the top quark mass to be 171.4 GeV. No tachyonic modes for sfermions are allowed at any energy scale. Gaugino masses have been treated as universal at high scale for simplification.

In this study the low energy sfermion masses vis-a-vis those of charginos and neutralinos primarily dictate the phenomenology. Relating them to high scale parameters is done for the purpose more in the way of illustration, and achieving a very high degree of precision in the relationship among low and high scale parameters is not of primary importance here. Thus, in the running of parameters, one-loop renormalization group equations (RGE) have been used. No low-energy radiative corrections to the chargino and neutralino masses matrices have been taken, which does not affect our analysis in any significant way [50]. Full one-loop and the dominant two-loop corrections to the Higgs masses are incorporated.

3.2 Numerical results

In figures 1 and 2, we have presented four ratios, namely, $OSD/jets$, $SSD/jets$, $(3\ell + jets)/jets$ and $3\ell/jets$. For $(m_{\tilde{g}}, m_{\tilde{q}^{1,2}})$ = (500,500) GeV, electroweak symmetry breaking conditions are not satisfied when the low-energy slepton mass is 500 or 750 Gev. This is because, with gaugino masses on the lower side, such large slepton masses require a rather large high-scale value for the slepton-Higgs mass parameter, which prevents $m^2_{H_u}$ from being driven to a negative value at the electroweak scale. For low slepton and high gaugino masses, on the other hand, the lighter stau eigenstate becomes the LSP for $\tan\beta$ = 40.

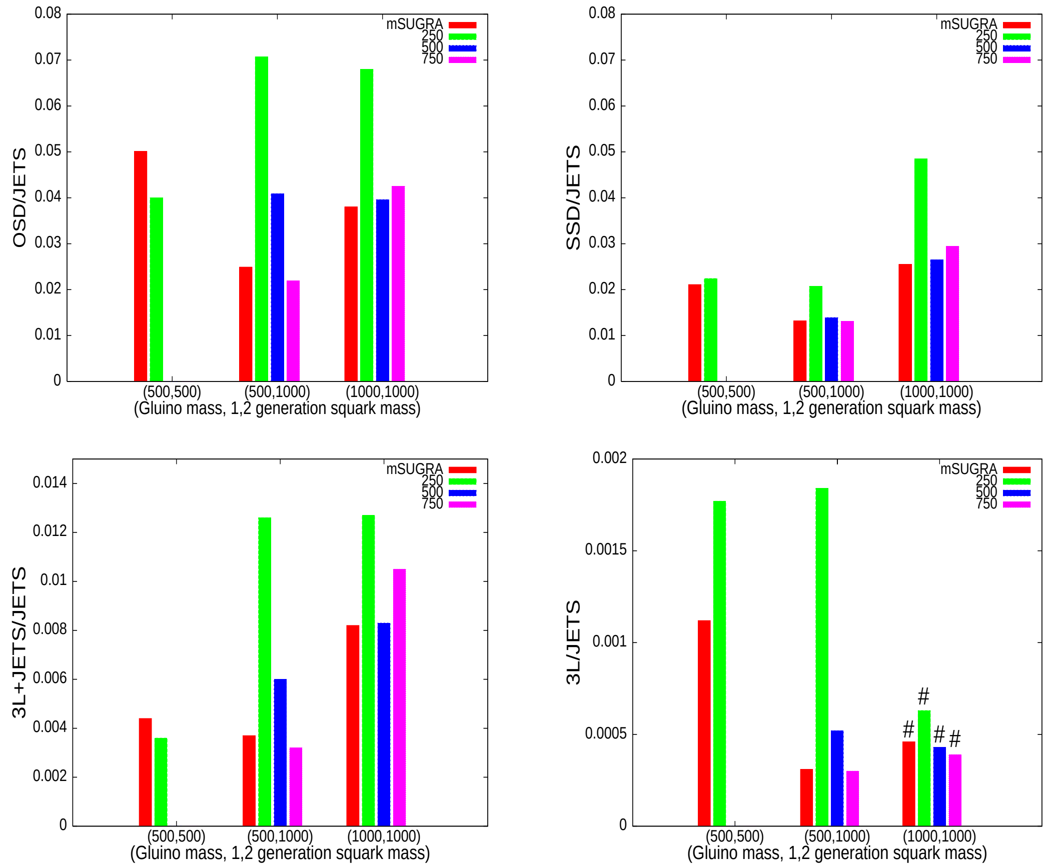

Figure 1: Event ratios for Squark-Slepton Non-universality: $\tan\beta = 5$

A survey of figures 1 and 2 reveals the following general features for the case with squark-slepton non-universality:

- The case with the lowest choice of slepton masses, namely, $m_{\tilde{l}1,2} = 250$ GeV, is fairly distinguishable from the others, especially for the squark masses on the higher side. This is primarily because low-lying sleptons participate in the chargino and neutralino cascades to yield more events with leptons in the final state. Such an effect is noticeable for $\tan\beta = 5$. One has to remember here that the chargino and neutralino mass matrices whose textures govern the cascades are also controlled by μ which is related to $m_{\tilde{l}1,2}$. Thus the final rates depend on a crucial interplay of the slepton mass parameter, the gaugino masses and $\tan\beta$, over and above the enhanced probability of on-shell decays of charginos and neutralinos into sleptons.

- Cases with $m_{\tilde{l}1,2} = 500$ GeV are by and large difficult to differentiate from a spectrum with universal scalar mass.

- The $3\ell + jets$ events allow one to distinguish cases with the slepton mass on the high

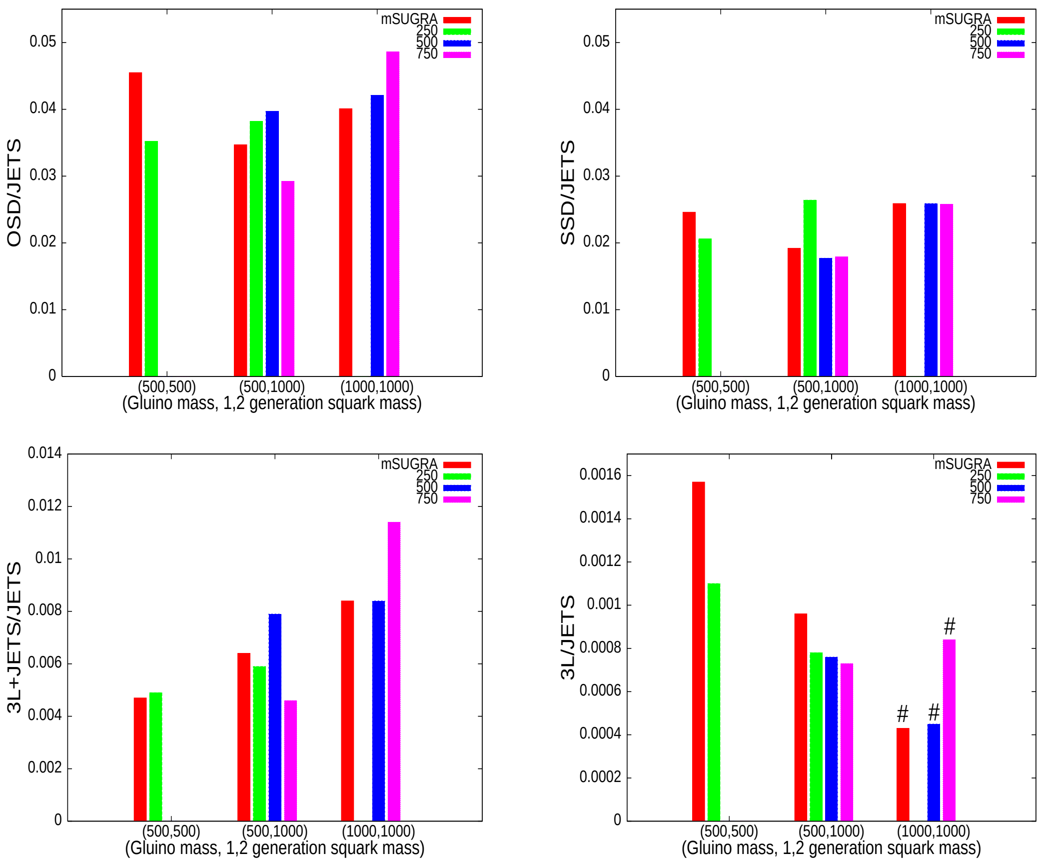

Figure 2: Event ratios for Squark-Slepton Non-universality: $\tan\beta = 40$

side, such as 750 GeV. This effect is more prominent for high gluino mass and large $\tan\beta$.

- The hadronically quiet trilepton signals give us sufficient distinction in cases where the background is not forbidding. This channel gets drowned in backgrounds only for $(m_{\tilde{g}}, m_{\tilde{q}^{1,2}})$ = (1000,1000) GeV. The universal case is best distinguished with one where the slepton mass of the first two families assumes the lowest chosen value (250 GeV). This is because these would help on-shell slepton production in two-body decays of charginos and neutralinos. Naturally, higher gluino masses hurt this channel because they mean higher chargino/neutralino masses and thus lower production rates with gaugino universality (see table B1 and B2). Moreover, the distinction is more prominent for $\tan\beta$ on the lower side.

- In general (including the difficult case mentioned above), trileptons in the final state are the most useful signals in distinguishing among different scenarios.

4. Non-universality in the third family

In order to address the FCNC problem that continues to haunt SUGRA-type models, it has sometimes been proposed that the first two families of squarks and sleptons are very heavy. This suppresses FCNC in most cases. At the same time, a third family of sfermions within a TeV suffices to provide a solution to the naturalness problem. Such scenarios have been theoretically motivated, for example, in string-inspired models, assuming flavour-dependent coupling to modular fields, or postulating that the masses of the third family scalars arise from a separate F-term vev. D-terms of an anomalous $U(1)$ symmetry have also been suggested for implementing such 'inverted hierarchy' [32–36].

Since this is a rather representative case of scalar non-universality, we have subjected the resulting spectra to the multichannel analysis outlined earlier. However, we do not confine ourselves to any special theoretical scenario, except assuming that scalar masses in the third family evolve from a separate high-scale mass parameter m_0^3, while a different parameter $m_0^{(1,2)}$ is the origin of scalar masses in the first two families.

4.1 Choice of parameters

As has been already mentioned, we have assumed the third family scalar masses to arise out of a separate parameter at high scale (m_0^3). The SUSY breaking mass parameters m_{H_u} & m_{H_d} in the Higgs sector are also assumed to originate in same parameter m_0^3. Otherwise, in cases where $m_0^{(1,2)}$ is very high and essentially decoupled, a correspondingly high value of the Higgs mass parameter(s) will make it difficult to obtain electroweak symmetry breaking in a consistent manner.

This allows one to fix the magnitude of the μ-parameter, which we have taken to be of positive sign throughout our analysis. As in the previous section, we have taken $A_0 = 0$. The unification of gaugino masses and gauge couplings at high scale has been ensured. As before, the **pMSSM** option in `SuSpect` has been used, and m_0^3 as well as the high-scale gaugino mass parameter has been tuned in such a way as to yield specific values of the gluino mass and the lighter stop mass ($m_{\tilde{t}_1}$) at low-energy. The chosen combinations of $(m_{\tilde{g}}, m_{\tilde{t}_1})$ are (500,500), (500, 1000) and (1000,1000), all masses being expressed in GeV. These values are used in the labels of the x-axis in figures 3 and 4.

For each combination mentioned above, two choices of $m_0^{(1,2)}$ have been made, corresponding to the average squark mass in the first two families equal to 1 TeV and 10 TeV, respectively, at the electroweak scale. It should be mentioned here that a parameter combination with $m_0^{(1,2)}$ of the order of a few TeV's and the third family squark masses around a few hundred GeV's is admissible even in an mSUGRA scenario, where the first two families of squarks can be missed at the LHC [51]. The results for such choices are juxtaposed with the universal SUGRA scenario tuned in such a way as to yield the same $(m_{\tilde{g}}, m_{\tilde{t}_1})$, in the bar graphs shown in figures 3 and 4. Two values of $\tan\beta$, namely, 5 and 40, have been used for every combination of masses (see table A3 and A4).

The procedure adopted in running the parameters is the same as that described in the previous section. All constraints on the low-energy parameters, including those from

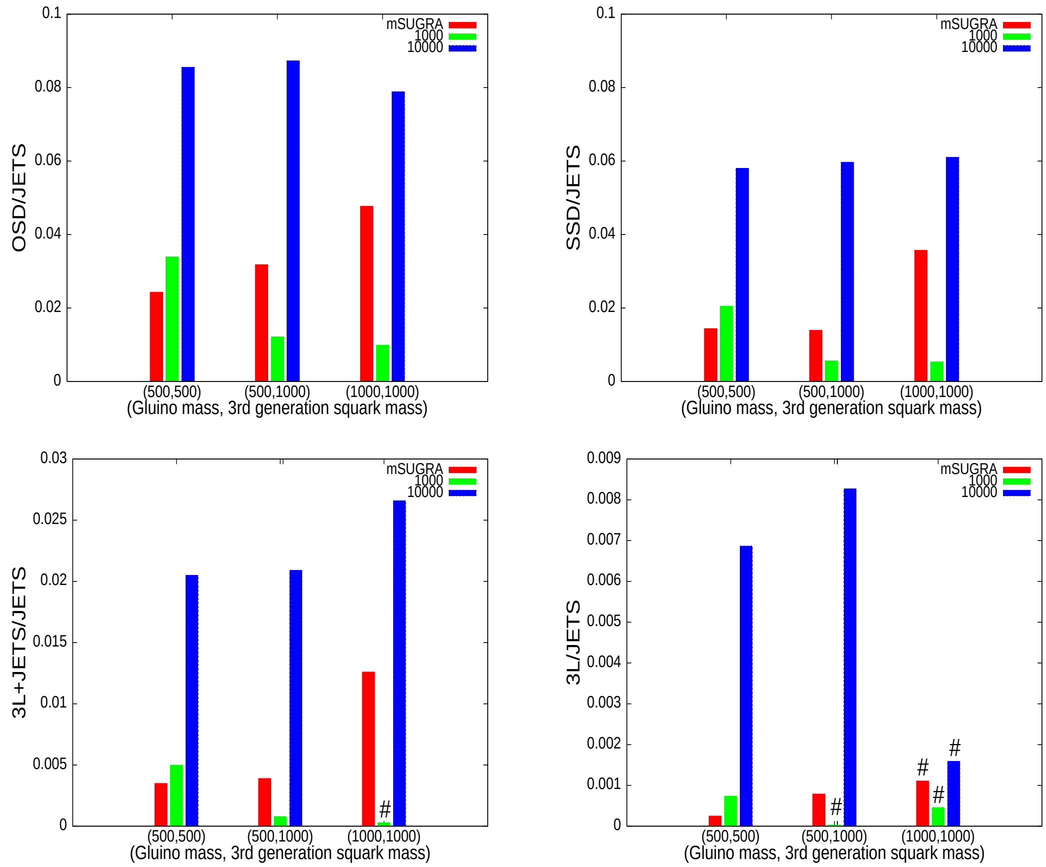

Figure 3: Event ratios for 3rd family scalar Non-universality: $\tan\beta = 5$

FCNC, have been satisfied in each case.

4.2 Numerical results

The general format of presentation of the numerical results in this case is similar to that adopted in the previous section. All the parameter combinations here are found to lead to consistent sparticle spectra, satisfying the electroweak symmetry breaking conditions and other necessary requirements.

The various event rates are influenced by some salient features of the spectrum. First of all, the high value of $m_0^{(1,2)}$ required to make the first two squark families as heavy as 10 TeV leaves little significance for gaugino corrections at low scale, resulting in the close degeneracy of squark and sleptons in the first two families. For the squark masses around 1 TeV for the first two families, on the other hand, one has to take a much smaller $m_0^{(1,2)}$, which leads to relatively light sleptons. For the third family, the effects of mixing and Yukawa coupling bring the lighter stop below all other sfermions, the difference being more pronounced for low $\tan\beta$ (see table in B3 and B4).

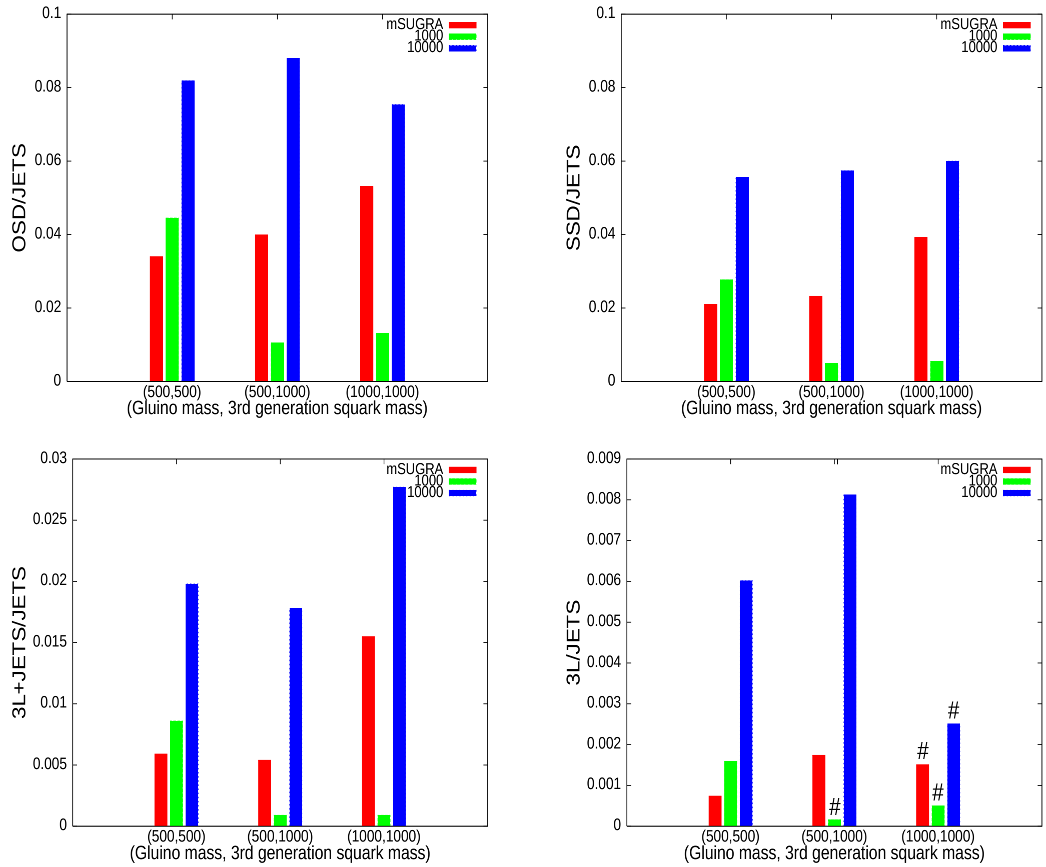

Figure 4: Event ratios for 3rd family scalar Non-universality: $\tan\beta = 40$

The following broad features can be seen in the results:

- The rate of leptonic events relative to the all-jet final state goes up significantly for higher masses for the first two generations, i.e. $m_{\tilde{q}^{1,2}} = 10$ TeV. This is because final states in the cases of decoupled first two families are dominated by the stop, which leads to more avenues of lepton production via top decay. The relative suppression of all-jet events from squark pairs (of the first two families) is also responsible for lower values of the denominators in different ratios.

- The leptonic final states for the non-universal case with $m_{\tilde{q}^{1,2}} = 1$ TeV get considerably depleted with respect to the corresponding universal cases, especially for relatively high third family squark masses. This happens as a result of our parametrization where we are matching the mass of the lighter stop between the two cases. While this means heavier squarks of the first two families in universal case, the non-universal case with $m_{\tilde{q}^{1,2}} = 1$ TeV gives such squarks in the same mass range. Therefore, they contribute more effectively to all-jet final states, leading to a depletion of leptonic

signals. This feature is reflected not only in the various ratios but also in the absolute values of the events rates.

- The difference between $m_{\tilde{q}^{1,2}} = 1$ TeV $m_{\tilde{q}^{1,2}} = 10$ TeV is most clearly noticeable for the trilepton channel.
- In a way similar to the other ratios, higher values of third family scalar masses facilitate distinction via the hadronically quiet channels. However, this channel does not really serve as a better discriminator than OSD, SSD, and inclusive trilepton final states for this type of non-universality. The underlying reason for this is again the enhancement of the latter through frequent occurrence of the top quark in SUSY cascades. Also, just as for squark-slepton non-universality, the hadronically quiet trileptons are suppressed by backgrounds for $(m_{\tilde{g}}, m_{\tilde{t}_1}) = (1000{,}1000)$ GeV.
- Unlike the other cases of non-universality studied in this paper the observed features bear very little imprint on the value of $\tan\beta$.

5. Non-universality due to $SO(10)$ D-terms

In the two previous sections, scenarios reflecting scalar non-universality have been considered in a purely phenomenological ways. Now we take up a specific theoretical model, namely one based on an $SO(10)$ SUSY Grand Unified Theory (GUT) [52].

In an $SO(10)$ framework, the matter fields belong to the representation **16**, and can be further classified into sub-multiplets, depending on the representations of $SU(5)$ to which they belong. In this classification, expressing the (s)fermions generically to include all families, the superfields D^c and L belong to $\bar{\mathbf{5}}$, while Q, U^c and E^c belong to **10**, where Q and L denote $SU(2)$ doublets and the others, singlets. The breakdown of $SO(10)$ (without any intermediate scale) to the SM gauge group, which amounts to a reduction of rank, will therefore endow the scalars in these different $SU(5)$ representations with different D-terms [37]. Consequently, the high-scale scalar mass parameters will be different for the two multiplets respectively for $\bar{\mathbf{5}}$ and **10**: [38, 39]

$$m_{\bar{5}}^2 = m_0^2 - 1.5Dm_0^2 \quad (for\ D^c\ \&\ L) \tag{5.1}$$

$$m_{10}^2 = m_0^2 + 0.5Dm_0^2 \quad (for\ E^c, U^c\ \&\ Q) \tag{5.2}$$

$$\tag{5.3}$$

thus leading to a predestined non-universality in the GUT scale itself. Here D is a dimensionless parameter quantifying the added contribution to the SUSY breaking terms in terms of the 'universal' high-scale mass parameter m_0.

5.1 Choice of parameters

We have restricted the value of D in order to avoid tachyonic modes at high scale. Thus D = 0.5, -0.5 and -1.25 have been taken, m_0 being fixed at 300 GeV. $M_{1/2}$ has been chosen in such a way as to obtain the low-scale gluino mass at 500 GeV, 1 TeV and 1.5 TeV.

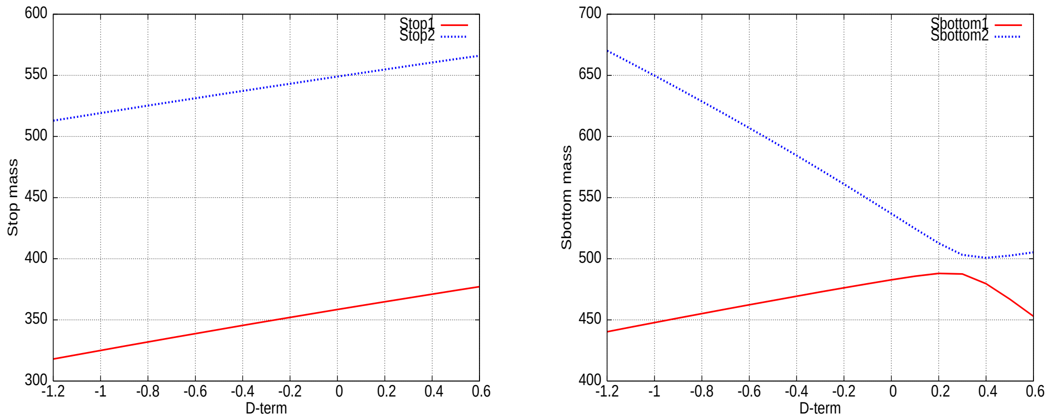

Figure 5: Variation of stop and sbottom mass with D-term:$\tan\beta = 5$

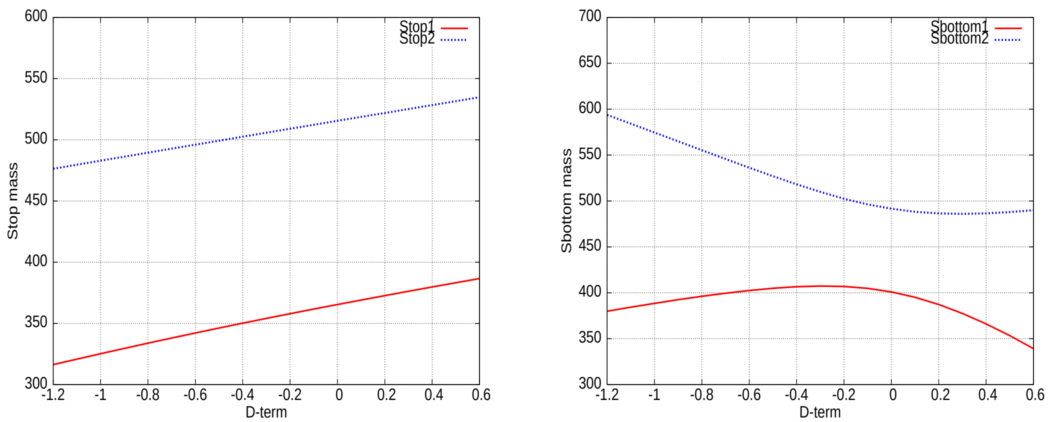

Figure 6: Variation of stop and sbottom mass with D-term:$\tan\beta = 40$

While the sign of μ has been kept positive in each case, we have again chosen $\tan\beta$ to be 5 and 40. The low-energy spectrum is the result of one-loop RGE following `Suspect`, with the **pMSSM** option (see table A5 and A6).

5.2 Numerical results

The low-energy masses of the right-chiral down-type squarks and left-chiral charged leptons fall as D is varied from the minimum to the maximum allowed value in the permissible range. In particular, the masses of the physical states in the third family as a function of D are shown in figure 5 for both $\tan\beta$= 5 and 40, because they bring in more complex behaviour due to mixing. It should be noted that the parabolic D-dependence of the masses are flattened out considerably due to running, since gauginos contribute to the low-energy scalar masses [50]. The two stop mass eigenstates vary in the same way with D, since both the t_L and t_R superfields belong to $\mathbf{10}$ of $SU(5)$, while b_R, unlike b_L, belongs to $\bar{\mathbf{5}}$. The

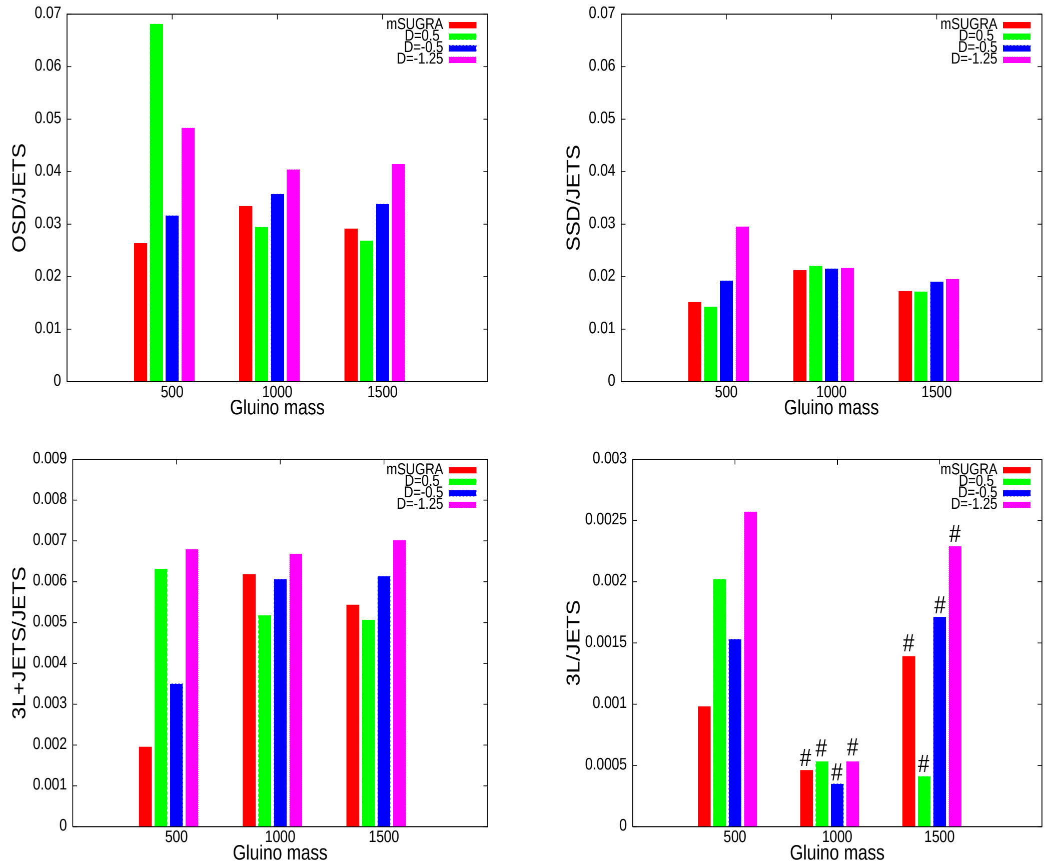

Figure 7: Event ratios for $SO(10)$ D-term Non-universality: $\tan\beta = 5$

last mentioned effect is responsible for different variation patterns of the two sbottom mass eigenstates.

In any case, the nature of non-universality is different from the two cases investigated earlier.

The same ratios as those studied previously are presented in this context, in figures 6 and 7. The three values of D mentioned above lead to the three non-universal bar graphs in each case, D =0 being the corresponding mSUGRA scenario. It may be noted that for D = -1.25, one ends up with a stau LSP for $m_{\tilde{g}}$ = 1 TeV, 1.5 TeV and $\tan\beta = 40$. The reason this does not happen for $m_{\tilde{g}}$ = 500 GeV is because the lowering of the lighter mass eigenstate is stalled by the low value of μ in the first case.

The main features that emerge from the ratio as well as the absolute rates are as follows:

- For high gluino masses such as $m_{\tilde{g}}$= 1 TeV and 1.5 TeV, the distinction between various non-universalities for D= 0.5, -0.5 and -1.25 becomes difficult from the ratio plot. This is because, for high value of $M_{1/2}$, the low energy squark-slepton masses

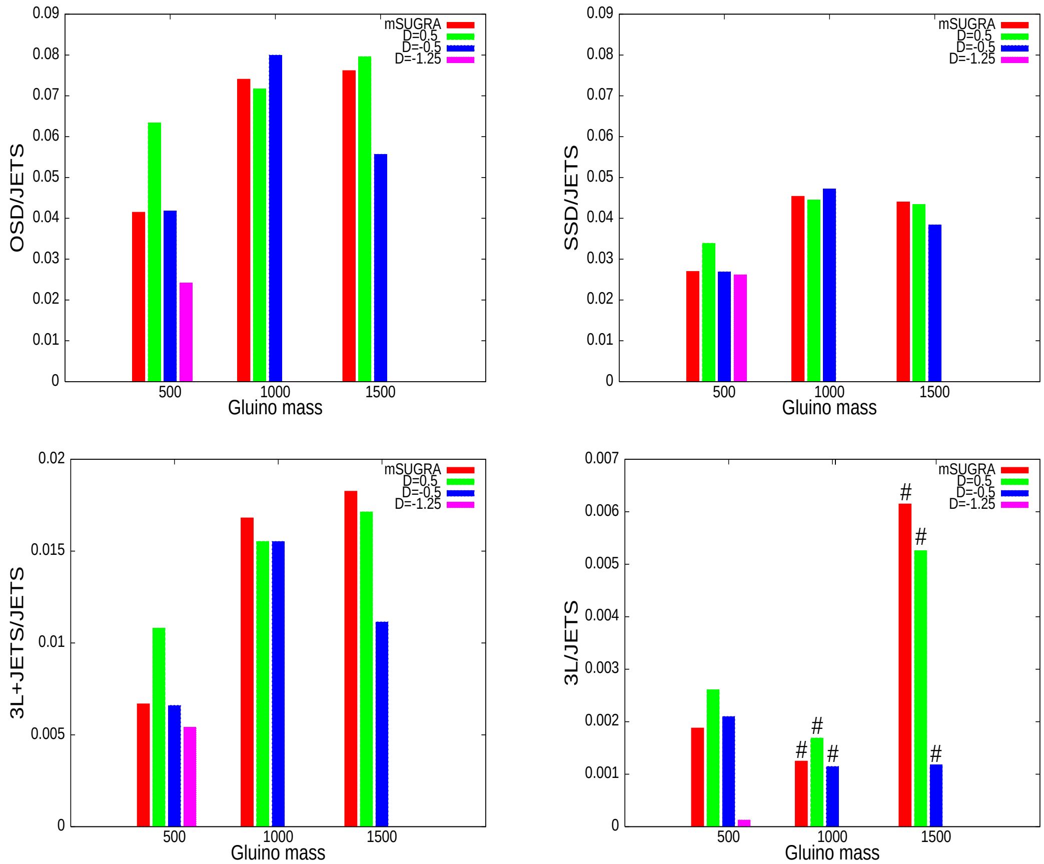

Figure 8: Event ratios for $SO(10)$ D-term Non-universality: $\tan\beta = 40$

are dominated by gaugino contributions, the effect of non-universal inputs to the scalar masses through D-terms being thus imperceptible. An exception to this occurs for $m_{\tilde{g}}$= 1.5 TeV and $\tan\beta$ = 40, due to the same reason as above, namely, the contribution to the off-diagonal term in the sbottom mass matrix through the μ-parameter determined by such gaugino masses.

- For $m_{\tilde{g}}$= 1 TeV and 1.5 TeV (particularly for $\tan\beta$ =5), the only channels that partly distinguish among various values of the $SO(10)$ D-term are $3\ell + jets$. This happens because whatever mass hierarchy between squarks and sleptons due to the D-terms is there is accentuated with the largest detectable number of leptons in the final state.

- For $m_{\tilde{g}}$= 500 GeV, $OSD/jets$ is a good discriminator along with the trileptonic channels. In particular, the cases of D=0.5 and D=-1.25 are easily distinguishable from the ratios. The ratio $SSD/jets$, on the other hand, is relatively flat, because these are initiated by the production of gluinos, where the effects of scalars are more often washed out.

- The hadronically quiet trilepton events are largely washed out by backgrounds, excepting for $m_{\tilde{g}}$= 500 GeV.

- For D=-1.25, the leptonic final states give almost always the largest fraction of events for $\tan\beta = 5$, while for $\tan\beta = 40$ the fraction is the smallest.

- The absolute numbers in various channels are also very efficient discriminators in this type of non-universal scenarios particularly for low gluino mass (see table B5 and B6).

6. Summary and conclusions

We have considered three representative scenarios where the scalar mass spectrum in SUSY can deviate from the predictions of a universal SUGRA model. These are situations with (a) high-scale non-universality of squarks and sleptons, (b) a separate high-scale mass parameter for the third family sfermions, and (c) the effect of $SO(10)$ D-terms. In each case, we have made a detailed scan of the parameter space, in terms of the gluino and squark masses which set the scale of the hard scattering leading to superparticle production. While the value of the μ parameter (upto a sign) has been mostly fixed from radiative electroweak symmetry breaking, we have chosen two representative values of $\tan\beta$ for our analysis, namely 5 and 40.

In essence, relatively low values of slepton masses in various schemes and in different regions of the parameter space buttress the leptonic final states. With this in view, a multichannel analysis including various leptonic final states has been performed in each case, comparing the different degrees of non-universality with the mSUGRA case. The ratios of the like- and opposite-sign dilepton rates as well as trileptons (with and without accompanying hard jets) with respect to the inclusive jet signal.

The case where the most conspicuous effects are seen in terms of the ratios is one where the the first two family squarks have masses on the order of 10 TeV. In addition, the absolute number of events for this situation is rather low compared to the other cases, which can serve as another distinguishing feature.

For the first two family squarks still within 1 TeV or so, however, the distinction with the case of squark-slepton universality gets somewhat blurred. This is because the masses of the first two families of squarks and sleptons are often in the same range, and thus the cascades leading to the leptonic final states are similar in nature. A marginal, though not spectacular, improvement is achieved by considering the absolute event rates. However, the ratios are more sensitive to the mass ranges of the squarks and gluinos within a given pattern of non-universality, and as such they can provide useful clues to the level at which a departure from universality has taken place. The distinction is even more difficult for $SO(10)$ D-terms, except for D = -1.25. For these values of D, distinction among various cases as well as with the universal case can be problematic.

The effect of $\tan\beta$ can also have important bearing on the various ratios an exception being in case of third family non-universality. Therefore, the independent extraction of $\tan\beta$ from Higgs boson signals is going to be useful in establishing scalar non-universality.

It is also seen that the trilepton events can be most useful in making distinction among different situations. So are hadronically quiet trleptons, so long as they are able to rise above backgrounds. Next in the order is the importance of opposite-sign dileptons. Thus the investigation of leptonic final states with increasing multiplicity, apart from the enhancing 'clean' character of the events, is likely to enlighten us on the issue of non-universality.

In addition to the different kinds of sfermion non-universality discussed in the previous sections, one could also think of the Higgs mass parameters evolving from a different common high-scale value compared to that determining the squark and slepton masses [53]. While this can affect Higgs phenomenology considerably, our multichannel analysis gets appreciably affected by such non-universality only when the charged Higgs state can be made very light. In such case, too, the rates in leptonic channels which are our main concern are altered if the charged Higgs can be produced on-shell in the decay of the stop or the sbottom , or of a chargino/neutralino. Although the charged Higgs mass is lowered around or below 200 GeV for some combinations of parameters including a large $\tan\beta$, effects of the above type are rare.

It should be noted at the end that, unlike in the case of gaugino non-universality [10], the schemes of parametrising scalar non-universality are more non-uniform. Therefore, different schemes often lead to overlapping portions in the spectrum, where signals may turn out to be of similar nature. The most significant departure from universality in terms of overall event rates can occur through the variation of masses of the first two family squarks, whereas the lepton-to-jet event ratios are influenced more substantially when the first two family sleptons have masses that are different from what is predicted in mSUGRA. These generic features of the scalar spectrum, rather than different theoretical schemes, are likely to be exposed more easily at the LHC.

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APPENDIX A

In this appendix we list the relevant masses in the spectrum. Specifically, we provide the high scale scalar inputs (which is specific to the kind of non-universal model) to generate the low energy scalar mass parameters. We provide the low lying chargino-neutralino masses as well. The tables are organised as follows: squark-Slepton non-universal case in A1 and A2, third generation scalar non-universality and in A3 and A4, and non-universality arising due to $SO(10)$ D-term in A5 and A6.

We would like to mention that for low energy $m_{\tilde{g}}$= 500 GeV, 1000 GeV, or 1500 GeV, high scale universal input for the gaugino masses $m_{1/2}$ are 166.9 GeV, 333.65 GeV and 500.5 GeV for 1-loop RGE and this is obviously independent of what kind of scalar non-universal model we are looking at.

NA indicates that the spectrum generated is inconsistent due to the reasons mentioned in the text accordingly.

Table A1 : Mass Spectrum (GeV) for squark-slepton non-universality
$\tan\beta$= 5
(Figure 1)

$(m_{\tilde{g}}, m_{\tilde{q}^{1,2}})$	$m_{\tilde{l}^{1,2}}$	$m_{0\tilde{q}}$	$m_{0\tilde{l}}$	$m_{\tilde{\chi}_2^\pm}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{t}_1}$	$m_{\tilde{b}_1}$	$m_{\tilde{\tau}_1}$
(500,500)	**225***	200	200	344	117	118	60	336	450	212
(500,500)	**250**	200	220	337	116	117	60	333	449	231
(500,500)	**500**	NA	NA	NA	NA	NA	NA	NA	NA	NA
(500,500)	**750**	NA	NA	NA	NA	NA	NA	NA	NA	NA
(500,1000)	**906***	900	900	546	126	127	62	558	818	900
(500,1000)	**250**	900	230	867	130	130	63	705	876	234
(500,1000)	**500**	900	490	799	130	130	63	672	862	491
(500,1000)	**750**	900	740	674	128	128	62	613	838	740
(1000,1000)	**450***	400	400	668	259	259	126	709	896	421
(1000,1000)	**250**	400	0	736	261	261	126	734	907	133
(1000,1000)	**500**	400	431	657	259	259	126	705	894	450
(1000,1000)	**750**	400	705	499	252	252	125	652	871	716

*** marked cases correspond to mSUGRA**

($m_{0\tilde{q}}$ and $m_{0\tilde{l}}$ are high scale non-universal inputs of squark and slepton mass)

Table A2 : Mass Spectrum (GeV)for squark-slepton non-universality

$\tan\beta = 40$

(Figure 2)

($m_{\tilde{g}}$,$m_{\tilde{q}^{1,2}}$)	$m_{\tilde{l}^{1,2}}$	$m_{0\tilde{q}}$	$m_{0\tilde{l}}$	$m_{\tilde{\chi}_2^{\pm}}$	$m_{\tilde{\chi}_1^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{t}_1}$	$m_{\tilde{b}_1}$	$m_{\tilde{\tau}_1}$
(500,500)	**225***	200	200	320	122	122	62	344	371	134
(500,500)	**250**	200	220	312	121	122	62	341	371	156
(500,500)	**500**	NA	NA	NA	NA	NA	NA	NA	NA	NA
(500,500)	**750**	NA	NA	NA	NA	NA	NA	NA	NA	NA
(500,1000)	**906***	900	900	457	129	129	63	578	684	731
(500,1000)	**250**	900	230	827	132	132	63	719	750	921
(500,1000)	**500**	900	490	752	132	132	63	687	734	381
(500,1000)	**750**	900	740	611	131	131	63	631	707	599
(1000,1000)	**450***	400	400	620	262	262	127	718	788	317
(1000,1000)	**250**	NA	NA	NA	NA	NA	NA	NA	NA	NA
(1000,1000)	**500**	400	431	607	262	262	127	714	787	344
(1000,1000)	**750**	400	705	423	251	251	126	661	769	572

*** marked cases correspond to mSUGRA**

($m_{0\tilde{q}}$ and $m_{0\tilde{l}}$ are high scale non-universal inputs of squark and slepton mass)

Table A3 : Mass Spectrum(GeV) for Third family scalar non-universality

$\tan\beta = 5$

(Figure 3)

($m_{\tilde{g}}$,$m_{\tilde{t}_1}$)	$m_{\tilde{q}^{1,2}}$	m_0^3	$m_0^{(1,2)}$	$m_{\tilde{\chi}_2^{\pm}}$	$m_{\tilde{\chi}_1^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{l}^{1,2}}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{b}_1}$
(500,500)	**876***	750	750	490	125	125	62	758	751	720
(500,500)	**1000**	750	900	490	125	125	62	906	751	720
(500,500)	**10000**	750	9990	490	125	125	62	9990	751	720
(500,1000)	**2050***	2000	2000	1024	131	131	63	2000	1995	1611
(500,1000)	**1000**	2000	900	1024	131	131	63	906	1995	1611
(500,1000)	**10000**	2000	9990	1024	131	131	63	9990	1995	1611
(1000,1000)	**1765***	1510	1510	973	263	263	126	1525	1512	1444
(1000,1000)	**1000**	1510	400	973	263	263	126	450	1512	1444
(1000,1000)	**10000**	1510	9990	973	263	263	126	9990	1512	1444

*** marked cases correspond to mSUGRA**

(m_0^3 and $m_0^{(1,2)}$ are high scale inputs of 3rd and 1,2 family non-universal scalar mass)

Table A4 : Mass Spectrum(GeV) for Third family scalar non-universality
$\tan\beta$= 40
(Figure 4)

($m_{\tilde{g}}$,$m_{\tilde{t}_1}$)	$m_{\tilde{q}^{1,2}}$	m_0^3	$m_0^{(1,2)}$	$m_{\tilde{\chi}_2^{\pm}}$	$m_{\tilde{\chi}_1^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{l}^{1,2}}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{b}_1}$
(500,500)	**876***	750	750	418	128	128	63	758	608	604
(500,500)	**1000**	750	900	418	128	128	63	906	608	604
(500,500)	**10000**	750	9990	418	128	128	63	9990	608	604
(500,1000)	**2050***	2000	2000	811	132	132	63	2000	1626	1331
(500,1000)	**1000**	2000	900	811	132	132	63	906	1626	1331
(500,1000)	**10000**	2000	9990	811	132	132	63	9990	1626	1331
(1000,1000)	**1765***	1510	1510	827	265	265	127	1525	1230	1236
(1000,1000)	**1000**	1510	400	827	265	265	127	450	1230	1236
(1000,1000)	**10000**	1510	9990	927	265	265	127	9990	1230	1236

*** marked cases correspond to mSUGRA**

(m_0^3 and $m_0^{(1,2)}$ are high scale inputs of 3rd and 1,2 family non-universal scalar mass)

Table A5 : Mass Spectrum(GeV) for $SO(10)$ D-term scalar Non-universality
High scale scalar mass input m_0=300 GeV
$\tan\beta$= 5
(Figure 6)

$m_{\tilde{g}}$	D-term	$m_{\tilde{\chi}_2^{\pm}}$	$m_{\tilde{\chi}_1^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{e}_L}$	$m_{\tilde{u}_L}$	$m_{\tilde{d}_R}$	$m_{\tilde{t}_1}$	$m_{\tilde{b}_1}$	$m_{\tilde{\tau}_1}$
500	**0.0***	361	118	119	60	328	548	537	358	483	308
500	**0.5**	386	120	121	60	201	568	470	374	467	200
500	**-0.5**	334	116	117	59	419	527	597	342	466	270
500	**-1.25**	291	110	112	58	526	494	676	316	438	198
1000	**0.0***	656	259	259	126	394	968	939	695	872	328
1000	**0.5**	670	259	259	126	297	980	903	703	880	287
1000	**-0.5**	641	259	259	126	472	956	975	686	863	292
1000	**-1.25**	619	258	258	126	569	939	1025	673	849	227
1500	**0.0***	965	396	396	190	485	1414	1368	1052	1281	359
1500	**0.5**	975	396	396	190	409	1422	1344	1057	1287	384
1500	**-0.5**	955	396	396	190	550	1406	1393	1047	1275	326
1500	**-1.25**	940	396	396	190	635	1394	1429	1039	1265	270

*** marked cases correspond to mSUGRA**

Table A6 : Mass Spectrum(GeV) for $SO(10)$ D-term scalar Non-universality
High scale scalar mass input m_0=300 GeV
$\tan\beta$= 40
(Figure 6)

$m_{\tilde{g}}$	D-term	$m_{\tilde{\chi}_2^{\pm}}$	$m_{\tilde{\chi}_1^{\pm}}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{e}_L}$	$m_{\tilde{u}_L}$	$m_{\tilde{d}_R}$	$m_{\tilde{t}_1}$	$m_{\tilde{b}_1}$	$m_{\tilde{\tau}_1}$
500	**0.0***	330	123	123	62	329	547	537	365	401	229
500	**0.5**	358	125	125	62	202	568	470	383	353	139
500	**-0.5**	301	120	121	62	419	526	597	346	405	184
500	**-1.25**	252	112	113	60	526	493	676	314	378	305
1000	**0.0***	612	262	262	127	395	968	940	704	767	229
1000	**0.5**	628	262	262	127	297	980	903	713	746	204
1000	**-0.5**	596	261	261	127	472	956	975	694	775	189
1000	**-1.25**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1500	**0.0***	905	398	398	191	485	1414	1369	1065	1151	250
1500	**0.5**	916	398	398	191	409	1422	1344	1071	1138	259
1500	**-0.5**	894	398	398	191	550	1406	1393	1059	1159	211
1500	**-1.25**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

*** marked cases correspond to mSUGRA**

APPENDIX B

Here we provide cross sections for all the channels in the three non-universal scenarios studied a) Squark-Slepton Non-universal case, b) 3rd generation scalar non-universality and c) Non-universality arising due to $SO(10)$ D-term respectively in three tables a) B1, B2 b) B3, B4 c) B5, B6. The SM background cross section is tabulated in B7.

The cross-sections are named as follows: σ_{OSD} for OSD, σ_{SSD} for SSD, $\sigma_{3\ell+jets}$ for $(3\ell+jets)$, $\sigma_{(3\ell)}$ for (3ℓ) and σ_{jets} for $jets$.

The cross-sections in bold font indicate that it is submergerd in the background as defined in text.

NA indicates that the spectrum is inconsistent as discussed early.

Table B1 : Cross-sections (pb) for squark-slepton non-universality
$\tan\beta = 5$
(Figure 1)

$(m_{\tilde{g}},m_{\tilde{q}^{1,2}})$	$m_{\tilde{l}^{1,2}}$	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
(500,500)	**mSUGRA**	0.4972	0.2100	0.0437	0.00111	9.3302
(500,500)	**250**	0.4144	0.2316	0.0367	0.01836	10.351
(500,500)	**500**	NA	NA	NA	NA	NA
(500,500)	**750**	NA	NA	NA	NA	NA
(500,1000)	**mSUGRA**	0.1782	0.0948	0.0266	0.00224	7.1574
(500,1000)	**250**	0.5218	0.1526	0.0931	0.01357	7.3764
(500,1000)	**500**	0.2989	0.1019	0.0440	0.00380	7.3032
(500,1000)	**750**	0.1593	0.0955	0.0231	0.00220	7.2698
(1000,1000)	**mSUGRA**	0.0277	0.0185	0.0060	**0.00034**	0.7277
(1000,1000)	**250**	0.0261	0.0186	0.0049	**0.00024**	0.3838
(1000,1000)	**500**	0.0289	0.0193	0.0060	**0.00032**	0.7285
(1000,1000)	**750**	0.0333	0.0231	0.0082	**0.00031**	0.7851

Table B2 : Cross-sections (pb) for squark-slepton non-universality
$\tan\beta = 40$
(Figure 2)

$(m_{\tilde{g}}, m_{\tilde{q}^{1,2}})$	$m_{\tilde{l}^{1,2}}$	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
(500,500)	**mSUGRA**	0.6267	0.3466	0.0665	0.02215	14.0742
(500,500)	**250**	0.5079	0.2971	0.0713	0.01585	14.4145
(500,500)	**500**	NA	NA	NA	NA	NA
(500,500)	**750**	NA	NA	NA	NA	NA
(500,1000)	**mSUGRA**	0.2388	0.1317	0.0441	0.00657	6.8736
(500,1000)	**250**	0.2730	0.1886	0.0422	0.00561	7.1379
(500,1000)	**500**	0.2798	0.1248	0.0556	0.00532	7.0394
(500,1000)	**750**	0.2037	0.1246	0.0319	0.00509	6.9650
(1000,1000)	**mSUGRA**	0.0314	0.0203	0.0066	**0.00034**	0.7839
(1000,1000)	**250**	NA	NA	NA	NA	NA
(1000,1000)	**500**	0.03323	0.0205	0.0066	**0.00036**	0.7900
(1000,1000)	**750**	0.0393	0.0209	0.0093	**0.00068**	0.8101

Table B3 : Cross-sections (pb) for Third family scalar non-universality
$\tan\beta = 5$
(Figure 3)

$(m_{\tilde{g}}, m_{\tilde{q}^{3}})$	$m_{\tilde{q}^{1,2}}$	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
(500,500)	**mSUGRA**	0.2190	0.1301	0.0316	0.00222	9.0107
(500,500)	**1000**	0.2365	0.1428	0.0351	0.00518	6.9707
(500,500)	**10000**	0.2535	0.1720	0.0608	0.02036	2.9642
(500,1000)	**mSUGRA**	0.1317	0.0574	0.0160	0.00325	4.1353
(500,1000)	**1000**	0.0949	0.0442	0.0067	**0.00027**	7.8590
(500,1000)	**10000**	0.2411	0.1649	0.0577	0.02284	2.7613
(1000,1000)	**mSUGRA**	0.0092	0.0069	0.0024	**0.00021**	0.1921
(1000,1000)	**1000**	0.0052	0.0028	**0.0002**	**0.00024**	0.5255
(1000,1000)	**10000**	0.0103	0.0080	0.0035	**0.00021**	0.1309

Table B4 : Cross-sections (pb) for Third family scalar non-universality
$\tan\beta = 40$
(Figure 4)

$(m_{\tilde{g}}, m_{\tilde{q}^3})$	$m_{\tilde{q}^{1,2}}$	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
(500,500)	**mSUGRA**	0.2971	0.1841	0.0515	0.00652	8.7476
(500,500)	**1000**	0.2894	0.1800	0.0563	0.01036	6.5057
(500,500)	**10000**	0.2557	0.1737	0.0617	0.01879	3.1213
(500,1000)	**mSUGRA**	0.1517	0.0882	0.0206	0.00663	3.8034
(500,1000)	**1000**	0.0835	0.0386	0.0068	**0.00131**	7.9259
(500,1000)	**10000**	0.2512	0.1639	0.0509	0.02318	2.8557
(1000,1000)	**mSUGRA**	0.0103	0.0076	0.0030	**0.00029**	0.1947
(1000,1000)	**1000**	0.0069	0.0029	0.0005	**0.00026**	0.5256
(1000,1000)	**10000**	0.0103	0.0082	0.0038	**0.00034**	0.1362

Table B5 : Cross-sections (pb) for $SO(10)$ D-term non-universality
$\tan\beta = 5$
(Figure 6)

$m_{\tilde{g}}$	D-term	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
500	**mSUGRA**	0.3720	0.2136	0.0276	0.01380	14.1440
500	**0.5**	0.3762	0.0782	0.0349	0.01120	5.5250
500	**-0.5**	0.3955	0.2402	0.0438	0.01916	12.5007
500	**-1.25**	0.5638	0.3438	0.0792	0.02999	11.6682
1000	**mSUGRA**	0.0251	0.0160	0.0046	**0.00035**	0.7530
1000	**0.5**	0.0221	0.0165	0.0039	**0.00040**	0.7519
1000	**-0.5**	0.0287	0.0173	0.0049	**0.00028**	0.8043
1000	**-1.25**	0.0341	0.0182	0.0056	**0.00045**	0.8456
1500	**mSUGRA**	0.0020	0.0012	0.0003	**0.00001**	0.0702
1500	**0.5**	0.0018	0.0012	0.0003	**0.00003**	0.0689
1500	**-0.5**	0.0024	0.0013	0.0004	**0.00012**	0.0709
1500	**-1.25**	0.0030	0.0014	0.0005	**0.00016**	0.0720

Table B6 : Cross-sections (pb) for $SO(10)$ D-term non-universality
$\tan\beta = 40$
(Figure 7)

$m_{\tilde{g}}$	D-term	σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
500	**mSUGRA**	0.5467	0.3360	0.0882	0.02482	13.1779
500	**0.5**	0.8111	0.4336	0.1383	0.03341	12.7985
500	**-0.5**	0.5552	0.3565	0.0898	0.02789	13.2670
500	**-1.25**	0.5731	0.6209	0.1283	0.0030	23.6538
1000	**mSUGRA**	0.0494	0.0303	0.0112	**0.00083**	0.6668
1000	**0.5**	0.0447	0.0278	0.0097	**0.00105**	0.6240
1000	**-0.5**	0.0505	0.0298	0.0098	**0.00073**	0.6309
1000	**-1.25**	NA	NA	NA	NA	NA
1500	**mSUGRA**	0.0041	0.0023	0.0010	**0.00033**	0.0532
1500	**0.5**	0.0043	0.0023	0.0009	**0.00028**	0.0537
1500	**-0.5**	0.0026	0.0018	0.0005	**0.00005**	0.0460
1500	**-1.25**	NA	NA	NA	NA	NA

Table B7 : Cross-sections (pb) for SM background

σ_{OSD}	σ_{SSD}	$\sigma_{(3\ell+jets)}$	$\sigma_{(3\ell)}$	σ_{jets}
0.1991	0.0900	0.0041	0.1920	2.1015